Crystalline Silicate Feature of the Vega-like star HD145263 [1]

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ABSTRACT

We have observed the 8-13 μm spectrum (R$\sim$250) of the Vega-like star candidate HD145263 using Subaru/COMICS. The spectrum of HD145263 shows the broad trapezoidal silicate feature with the shoulders at 9.3 μm and 11.44 μm, indicating the presence of crystalline silicate grains. This detection implies that crystalline silicate may also be commonly present around Vega-like stars. The 11.44 μm feature is slightly shifted to a longer wavelength compared to the usual 11.2-3 μm crystalline forsterite feature detected toward Herbig Ae/Be stars and T Tauri stars. Although the peak shift due to the effects of the grain size can not be ruled out, we suggest that Fe-bearing crystalline olivine explains the observed peak wavelength fairly well. Fe-bearing silicates are commonly found in meteorites and most interplanetary dust particles, which originate from planetesimal-like asteroids. According to studies of meteorites, Fe-bearing silicate must have been formed in asteroidal planetesimals, supporting the scenario that dust grains around Vega-like stars are of planetesimal origin, if the observed 11.44 μm peak is due to Fe-bearing silicates.

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1. Introduction

Recent mid-infrared observations have revealed that crystalline silicates are present in circumstellar disks around young stars (e.g. Hanner et al. 1995; Malfait et al. 1998; Sitko et al. 1999; Meeus et al. 2001; Bouwman et al. 2001; van Boekel et al. 2003; Honda et al. 2003; Meeus et al. 2003; Przygodda et al. 2003). Observed dust features indicate that the major composition of crystalline silicate is Mg-pure olivine, forsterite (Mg_2SiO_4) (e.g. Malfait et al. 1998). The observed 69 μm feature strongly supports the presence of forsterite (Molster et al. 2002; Bowey et al. 2002) and places a strong upper limit on the Fe-content in crystalline silicate grains (Fe/(Mg+Fe)<5%). Furthermore, the remarkable similarity between the spectrum of the isolated Herbig Ae/Be star HD100546 and that of the comet Hale-Bopp indicates that cometary dust is also Mg-rich silicate (Crovisier et al. 1997; Malfait et al. 1998; Wooden et al. 1999). This result is consistent with the *in situ* measurements of Comet Halley dust by PUMA mass spectrometry (Brownlee et al. 1987). Further, Bradley et al. (1999) reported that interplanetary dust particles (IDPs) originated from comets, such as the anhydrous chondritic porous (CP) "pyroxene" class of IDPs, contain mostly Mg-pure silicate grains (forsterite and enstatite). On the other hand, chondritic meteorites and most IDPs which have records of early solar system processing, show a variety of silicates. Not only Mg-rich olivine but also Fe-bearing fayalitic olivine are commonly present. In meteorites which probably came from asteroids, Fe-bearing silicate is ubiquitos (e.g. Krot et al. 2000). Many IDPs, which originate from either asteroids or comets, also show various Mg-Fe silicates (Bradley et al. 1999). However, there is no evidence for Fe-bearing crystalline silicate grains from astronomical observations so far (Suto et al. 2002).

Debris dust disk around Vega-like stars are supposed to be continuously replenished from planetesimals and/or comets (Lagrange et al. 2000). Thus one can expect that not only Mg-rich crystalline silicate but also Fe-bearing crystalline silicate grains might be present in the debris disk. Among Vega-like stars, compositional studies of silicate dust are rather scarce. The presence of crystalline silicate is reported only for βPic (Knacke et al. 1993; Weinberger et al. 2003; Okamoto et al. 2004), and no Fe-bearing crystalline silicate grains are reported.

In this Letter, we show the 8-13 μm spectrum of the Vega-like star candidate HD145263, and present a possible hint for Fe-bearing crystalline silicate. HD145263 is an F0V star at a distance of 116 pc (Sylvester et al. 2000), and was originally reported as a Vega-like star candidate by Mannings and Barlow (1998). It is located close to the zero-age main-sequence (ZAMS) in the HR diagram (Sylvester et al. 2000). It has L_{IR}/L_* of 0.02 which is smaller

than typical Herbig Ae/Be stars and T Tauri stars, but larger than prototype Vega-like stars (Lagrange et al. 2000). Thus it could be a young Vega-like star. It is also a member of the Upper Scorpius association whose age is estimated to be 8-10 Myr (Sartori et al. 2003), further supporting that HD145263 is a young Vega-like star.

2. Observations and Data Reduction

HD145263 was observed with the Cooled Mid-Infrared Camera and Spectrometer (COMICS; Kataza et al. 2000; Okamoto et al. 2003; Sako et al. 2003) mounted on the 8.2m SUBARU Telescope on July 15, 2003. N-band low-resolution (R$\sim$250) spectroscopic observations were performed with the 0.33” wide slit. Imaging photometry observations in the 8.8 μm ($\Delta\lambda$=0.8 μm) and 12.4 μm ($\Delta\lambda$=1.2 μm) bands were also made. We selected HD133774 (Cohen et al. 1999) as the ratioing star for the correction of the atmospheric absorption and as the flux standard star for the aperture photometry. The absolute flux of the standard star is obtained by integrating the template spectra provided by Cohen et al. (1999). The observation parameters are summarized in Table 1.

Standard reduction procedures as described in Honda et al. (2003, 2004) were applied for aperture photometry and spectroscopic data. The wavelength uncertainty is estimated to be 0.0025 μm (Okamoto et al. 2003). The effect of different airmass between the object and the standard star was corrected using the atmospheric transmission spectra calculated by the ATRAN software (Lord 1992). Finally we adjusted the flux of the spectrum of the HD145263 to the flux measured in the 8.8 μm and 12.4 μm bands respectively to correct the slit throughput. Detailed descriptions of the reduction procedures are given in Honda et al. (2003, 2004)

3. Results

Figure 1 shows the observed 8-13 μm spectra of HD145263 together with the T Tauri star Hen 3-600A (Honda et al. 2003) for comparison. HD145263 shows a broad trapezoidal silicate emission feature with the shoulders at 9.3 μm and 11.44 μm. This shape indicates the presence of crystalline silicate dust species in this system. Thus this is the second detection of crystalline silicate grains around Vega-like stars after β Pic. However, the spectrum is rather smooth between 9.3 μm and 11.44 μm, which is unusual for typical crystalline silicate features. According to laboratory measurements of fine grained crystalline forsterite particles (Koike et al. 2003), the sub-peak at 10.1 μm should be observed in addition to the 11.24 μm

strong peak if it is attributed to forsterite grains (see Fig.2). Furthermore, the 11.44 μm peak is clearly shifted to a longer wavelength compared to the forsterite 11.24 μm feature that has been seen toward many Herbig Ae/Be stars and T Tauri stars. The 11.44 μm feature may be attributed to 1) the presence of other dust species which account for the feature, or 2) the peak shift of the 11.24 μm forsterite feature due to the effect of the dust temperature, shape, and/or size.

Candidate dust species which might account for the 11.44 μm feature are, for example, fayalitic olivine (e.g. Fo20 or fayalite in Koike et al. (2003)) and diopside (Koike et al. 2000). They have features at around 11.4 μm. In order to reproduce the observed 11.44 μm feature and overall silicate emission of HD145263, we made a simple profile fitting. The fitting formula is given by

$$\lambda F_\lambda = (a_0 + \sum_{i=1} a_i \kappa_i)(\frac{\lambda}{9.8[\mu m]})^n,$$

where κ_i is mass absorption coefficient of dust and a_i are the fitting parameters. At first, we considered the following 4 dust species that were originally proposed by Bouwman et al. (2001) for reproducing the silicate feature of Hebig Ae/Be stars : 0.1 μm and 2.0 μm glassy olivine ($MgFeSiO_4$; Mie calculations using optical constant by Dorschner et al. 1995), crystalline forsterite (Mg_2SiO_4; absorption measurements by Koike et al. 2003), and silica (SiO_2; CDE calculations using optical constant by Spitzer & Kleinman 1961) grains. Their spectral profiles are shown in Honda et al. (2003). Resulting best-fit model spectra are shown in Figure 3 and the reduced χ squared (χ^2_ν) are summarized in Table 2. The combination of the "standard" 4 dust species can not provide acceptable fitting results. The 11.44 μm shoulder is not well reproduced. To improve the model spectrum, we introduce the fifth component : diopside (Koike et al. 2000), Fo40, Fo21.8, and fayalite (Koike et al. 2003) (Figure 2). The fitting results are also summarized in Table 2 and Figure 3. From Table 2, fayalitic olivine provides the best fit result. This is because fayalitic olivine has a feature at 11.4 μm and makes the total spectrum between 9.3 and 11.44 μm flatter if it coexists with forsterite. The presence of fayalitic olivine can account for the feature in the 10 μm spectrum of HD145263 fairly well.

On the other hand, there are alternative possibilities that could account for the 11.44 μm feature. The peak wavelengths of crystalline silicate features depend on the dust physical parameters (Molster et al. 2002) such as the temperature (Chihara et al. 2001; Bowey et al. 2001), the shape, and the size (e.g. Fabian et al. 2001; Min et al. 2003). The feature wavelength generally shifts to longer wavelengths as the grain temperature increases. However, Henning & Mutschke (1997) reported that the temperature effect for the crystalline silicate (bronzite) feature at 10 μm band is very small. Recent preliminary laboratory measurements show that the amount of peak shift ($\Delta\lambda$) between 50K and 300K for the 11.24 μm forsterite

feature is about $\sim$0.01 μm (Suto et al., private communication), indicating that the temperature effect only can not explain the 11.44 μm feature even at the forsterite sublimation temperature ($\sim$1400 K, $\Delta\lambda < 0.2\,\mu$m). Further, lack of excess emission in the near infrared from the spectral energy distribution of the HD145263 (Sylvester et al. 2000) indicates that there is little hot dust and it is difficult to expect the peak shift due to the grain temperature effect. Very elongated forsterite ellipsoids (prolates of aspect ratio of 10 $\sim$ 100) have the feature around 11.4 μm (Fabian et al. 2001), but the presence of such grain shape is unlikely according to the experimental study of fragments from collisional disruption (Fujiwara et al. 1978; Capaccioni et al. 1984; Fujiwara et al. 1989). Large (a few micron) crystalline forsterite grains have the possibility to account for the 11.44 μm shoulder. Large grains tend to broaden the feature and shift the peak to a longer wavelength (Molster et al. 2002). Although detailed studies of optical properties of large ellipsoidal crystalline silicate grains are needed to quantitatively investigate this possibility, large crystalline forsterite grains seem to be able to account for the peak shift to the $\sim$11.4 μm (Min et al. 2004).

To summarize, the observed 11.44 μm feature detected in HD145263 can be accounted for by either size or Fe-inclusion effects of olivine grains, or both. While the presence of large grains is not unexpected for Vega-like stars since its dust is replenished from much larger bodies, the presence of Fe-bearing silicate is also likely to occur. In the following section, we focus on the possibility and consequence of Fe-bearing olivine grains.

4. Discussion

Silicate material in planetesimals should undergo substantial alterations by thermal metamorphism through dust accumulating process or radioactive decay of species like ^{26}Al in them (e.g. Huss al. 2001). Such alterations are likely to lead to (partial) crystallization of silicate. Thus one can expect that crystalline silicate dust may appear when grains are supplied from the collisions of planetesimals, as is the case for the Vega-like stars. A similar origin for the crystalline silicate dust around the old Herbig Ae/Be star HD100546 and the comet Hale Bopp was proposed by Bouwman et al. (2003). The presence of crystalline silicate dust around the Vega-like star HD145263 supports the above hypothesis that crystalline silicate grains may be common in debris disks. However, this situation seems not to be the case for βPic, which is another Vega-like star with a signature of crystalline silicate (Okamoto et al. 2004). The crystalline silicate grains around βPic are suggested to be formed in the vicinity of the central star, but not in the planetesimals. Thus the origin for the crystalline silicate grains around Vega-like stars seem to have a variety.

HD145263 spectrum indicates a possible presence of Fe-bearing crystalline silicates,

while the crystalline silicate in the younger precursors such as T Tauri stars and Herbig Ae/Be stars is Mg-pure or Mg-rich, supporting the asteroidal plantesimal origin for crystalline silicate grains around HD145263. What is the origin of the Fe-bearing crystalline silicates? The dust around Vega-like stars is supposed to be of asteroidal planetesimals and comets (Lagrange et al. 2000). Cometary silicate grains are indicated to be Mg-rich based on the *in situ* measurements of the comet Halley dust (Brownlee et al. 1987), infrared observations of comet Hale Bopp (Crovisier et al. 1997; Malfait et al. 1998; Wooden et al. 1999), and studies of the anhydrous chondritic porous "pyroxene" class of IDPs which may be of cometary origin (Bradley et al. 1999). On the other hand, among the meteorites which came from asteroids, the presence of Fe-bearing silicate material is quite common (e.g. Krot et al. 2000) and Mg-pure silicate (forsterite and enstatite) grains are minor constituents of them (Bradley et al. 1999). According to studies of meteorites (Krot et al. 2000, and references therein), fayalitic olivine in meteorites is likely to have been formed in planetesimal-like parent bodies by low-temperature (∼500K) alteration under the presence of aqueous solution, because the formation of fayalitic olivine in a gas of solar composition is kinetically difficult or inhibited. Though condensation from a gas more oxidized than the solar gas may also lead to fayalitic olivine formation, such processes have difficulties to account for all the observed characteristics of meteorites (Krot et al. 2000). If fayalitic olivine is really formed in the asteroidal planetesimals, the presence of fayalitic olivine grains suggets mineralogical evidence that grains are indeed of asteroidal planetesimal origin.

To make solid detection of Fe-bearing olivine grains, observations at longer wavelengths are crucial. Accroding to Koike et al. (2003), similar peak shifts to longer wavelengths for longer wavelength bands ($> 20\,\mu$m) should be observed when Fe-bearing crystalline silicate grains really exist. Observations using Spitzer Space Telescope and Astro-F are strongly desired to provide decisive data.

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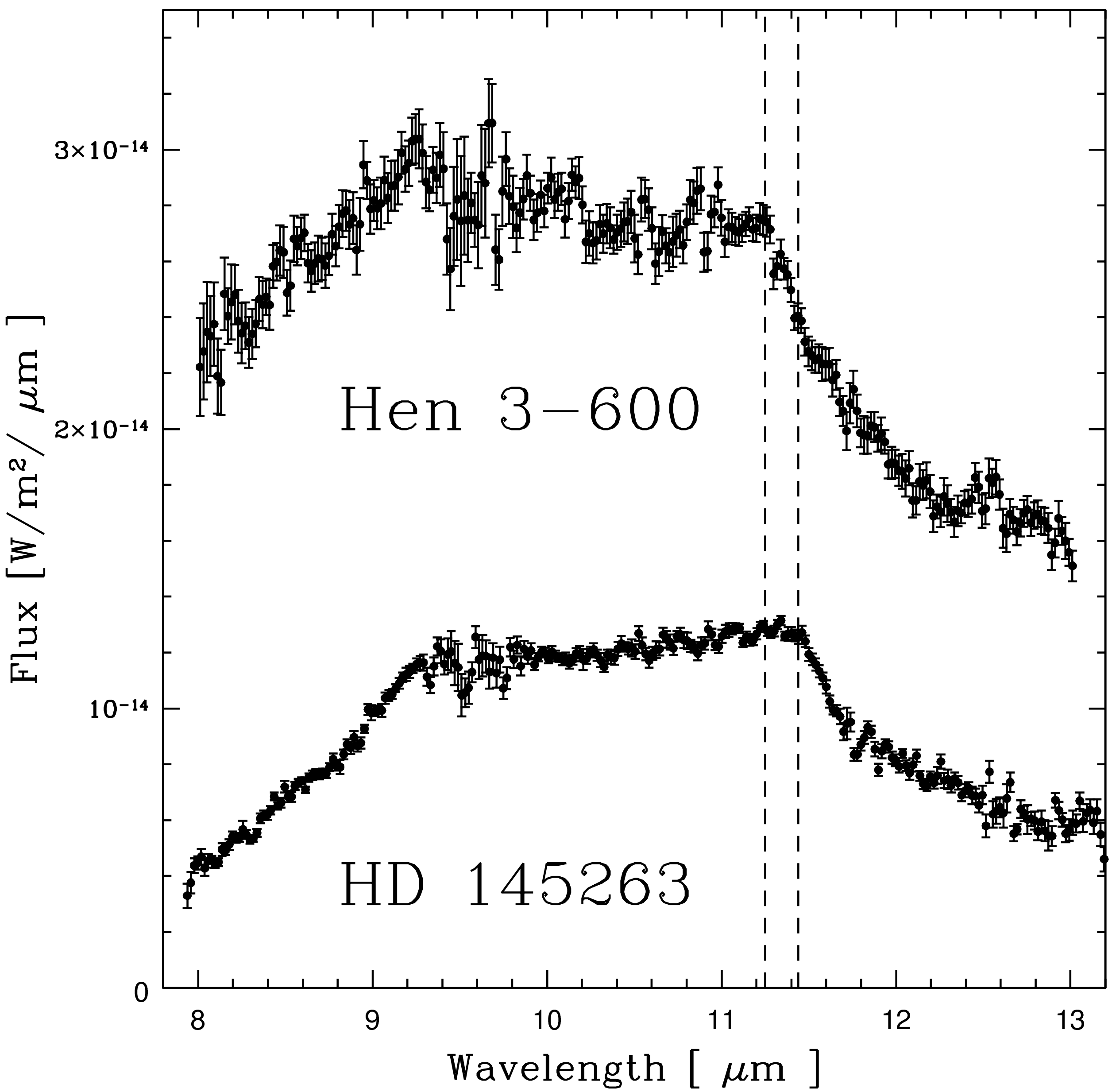

Fig. 1.— Observed 8-13 μm spectrum of the Vega-like star candidate HD145263 (lower spectrum) together with the T Tauri star Hen 3-600A (upper spectrum) for comparison (Honda et al. 2003). Large scatter in the 9.3-9.9 μm region is due to the atmospheric ozone absorption. HD145263 shows the 11.44 μm shoulder, while Hen 3-600A shows the 11.24 μm forsterite feature.

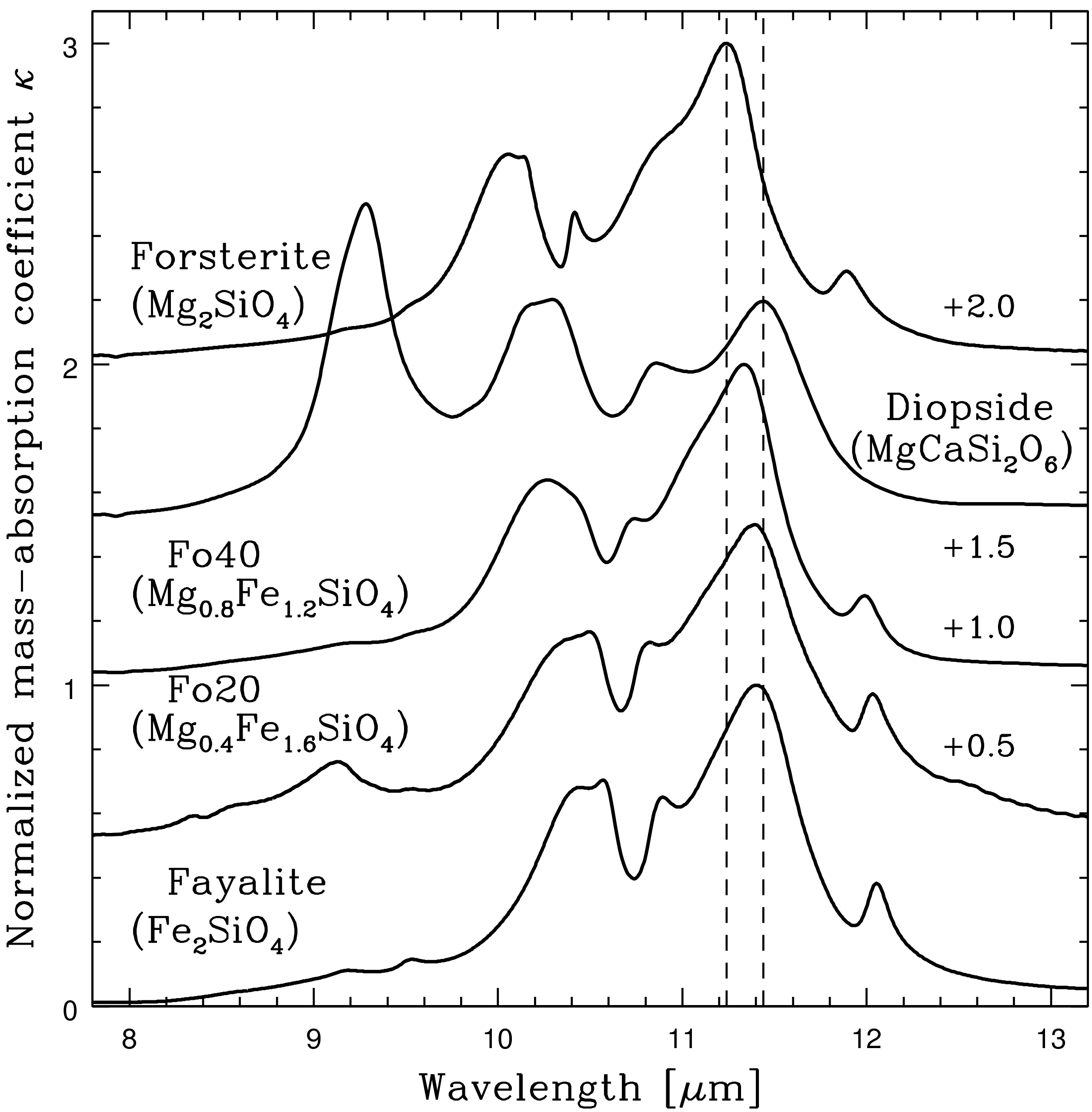

Fig. 2.— Normalized spectral profiles of the candidate dust species for the spectrum of HD145263. The data of forsterite, Fo40, Fo21.8, fayalite (Koike et al. 2003) and diopside (Koike et al. 2000) are taken from laboratory absorption measurements.

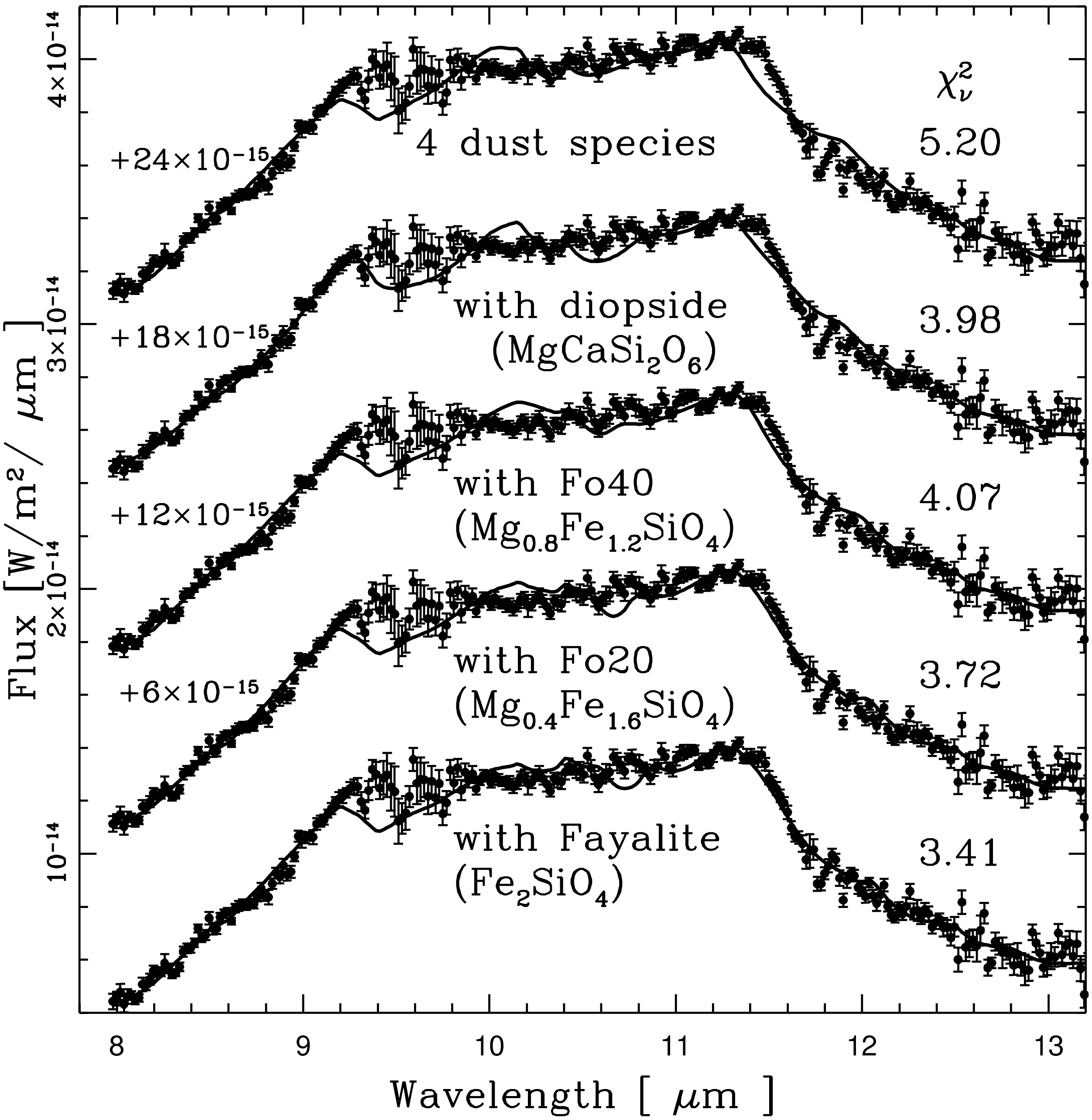

Fig. 3.— Observed spectrum of HD145263 together with model fit results of various dust combinations. The solid lines indicate best fit result for the each dust combination as described in Table 2. As seen in this figure, the dust combination included with fayalitic olivine provide the best fit result.

Table 1. COMICS Observations of the Vega-like star candidate HD145263

Date	Mode	Object	Filter [μm]	Integ. Time[sec]	Air Mass
July 15, 2003	Imaging	HD145263	8.8($\Delta\lambda$ =0.8)	40.2	1.427
		HD145263	12.4($\Delta\lambda$ =1.2)	60.9	1.425
		HD133774	8.8($\Delta\lambda$ =0.8)	5.0	1.452
		HD133774	12.4($\Delta\lambda$ =1.2)	4.1	1.462
	Spectroscopy	HD145263	-	1898.4	1.423-1.444
		HD133774	-	10.8	1.440

Table 2. Combination of dust species and reduced χ squared (χ^2_ν) for best fit

0.1 μm a. oliv.	2.0 μm a. oliv.	forsterite	silica	diopside	Fo40	Fo21.8	fayalite	χ^2_ν
$\surd$	$\surd$	$\surd$	$\surd$					5.20
$\surd$	$\surd$	$\surd$	$\surd$	$\surd$				3.98
$\surd$	$\surd$	$\surd$	$\surd$		$\surd$			4.07
$\surd$	$\surd$	$\surd$	$\surd$			$\surd$		3.72
$\surd$	$\surd$	$\surd$	$\surd$				$\surd$	3.41